Lasers Homework Activity

Learning Goals: Know the requirements needed to make a laser and the physical reason for each requirement.

In this activity, you will work through the requirements needed to make a laser, and think about how you can rework a laser design given adverse conditions. You will be working with the Lasers simulation to really discover and understand the requirements and operational considerations yourself.

a. (0.5 pts each) A laser involves the various processes by which light interacts with atoms: absorption, spontaneous emission, and stimulated emission. Which of the following descriptions accurately describes each process:

i. The process in which the electron naturally jumps down from a higher energy state to a lower state and spits out a photon corresponding to the energy difference as it does so:

☐ absorption ☐ spontaneous emission ☐ stimulated emission

ii. The process where a photon hits an atom that is in a higher energy level already and this causes the atom to spit out a photon that is identical to the one that hit the atom so there are two identical photons:

☐ absorption ☐ spontaneous emission ☐ stimulated emission

iii. The process by which the light is absorbed and the energy causes the atomic electron to go to a higher energy level:

☐ absorption ☐ spontaneous emission ☐ stimulated emission

b. (1 pt) A laser is created by producing a lot of photons created by stimulated emission. What characteristics make light produced by stimulated emission so special compared to light produced through spontaneous emission? (check all that apply)

☐ Photons are traveling exactly in the same direction.

☐ Photons' electromagnetic waves are oscillating exactly in phase.

☐ Photons are all exactly the same color.

☐ Photon has more energy

c. Open the One Atom Panel in the Laser Simulation and start exploring the **two-level atom**. All the questions in parts c. and d. are considering only the two-level atom (which is a good approximation to the behavior of real atoms when the conditions are such that the atoms are being excited to only one excited energy level).

i. (0.25 pts) For absorption to occur, the photon energy needs to:

☐ be equal to or greater than the energy difference between the two levels

☐ exactly match the energy difference between the two levels

☐ be equal to or less than the energy difference between the two levels.

ii. (0.25 pts each)

☐ True ☐ False In spontaneous emission, the photon is emitted in a random direction.

☐ True ☐ False In stimulated emission, the direction of the emitted photon is independent of the direction of the stimulating photon.

☐ True ☐ False When the conditions are such that there is a lot of stimulated emission, there is a net increase in the number of photons compared to the number emitted by the lamp.

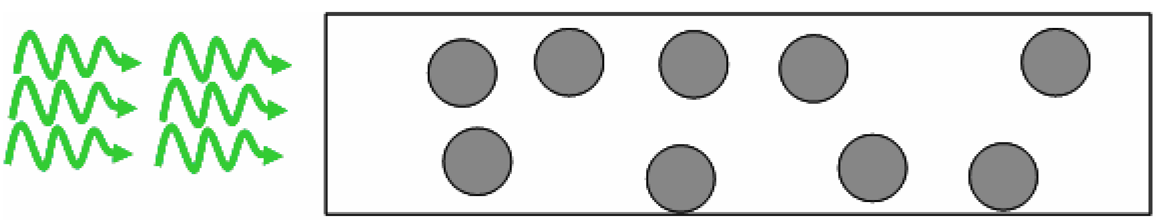
iii. (0.5 pts) Decreasing the lifetime of the upper energy level, (check all that apply)

- ☐ increases the average amount of time before an excited atom will undergo spontaneous emission
- ☐ decreases the average amount of time before an excited atom will undergo spontaneous emission
- ☐ increases the likelihood of spontaneous emission, and decreases the likelihood of stimulated emission
- ☐ decreases the likelihood of spontaneous emission, and increases the likelihood of stimulated emission
- ☐ increases the energy of that level
- ☐ decreases the energy of that level
- ☐ increases the wavelength of the photon needed to create stimulated emission of an atom in that level
- ☐ decreases the wavelength of the photon needed to create stimulated emission of an atom in that level

iv. (0.5 pts) Changes that will increase the likelihood that the excited atom will undergo stimulated emission include: (check all that apply)

- ☐ decreasing the lifetime of the excited state
- ☐ increasing the lifetime of the excited state
- ☐ increasing the lamp intensity
- ☐ decreasing the lamp intensity
- ☐ increasing the wavelength of light coming out of the lamp (assume you start at a wavelength where stimulated emission does occur)
- ☐ decreasing the wavelength of light coming out of the lamp (assume you start at a wavelength where stimulated emission does occur)

d. In a laser, a whole bunch of identical photons are created by stimulated emission.



(0.5 pts) We have an atom with only two relevant energy levels as in the two-level simulation, an excited state and a ground state. We send in these 6 photons (which match the energy difference between the levels). In order to get a net increase in the number of photons at the exit of this gas cell, what does the population of atoms need to be inside the cell:

- ☐ More than half need to be in the ground state
- ☐ Need half in the ground state, half in the excited state
- ☐ More than half need to be in the excited state

(0.5 pts) If we shine a sustained beam of these green photons through this cell, what will the average population distribution of atoms in the cell look like?

- All atoms will be in the excited state
- All atoms will be in the lower state
- Half the atoms will be in the lower state and half will be in the excited state

e. Open the **Multi-Atom Panel** in the Laser Simulation and start exploring. Now it's time to create a laser. Remember the goal of a laser is to build up a lot of *identical* photons. Play around with the different settings to figure out the requirements to create a laser. Make a laser so powerful that it blows up! (If you cannot, you haven't figured out how to make a laser.) If you go through this exploration, while paying attention to what is happening as you change different things, the questions below should be easy.

(0.5 pts) The number of energy levels needed:

- Two levels
- Three levels
- Either two or three levels

(2 pts) Check all that facilitate or are necessary for making a laser:

- [ ] Highish intensity of pumping light source (e.g. the colored flashlights)
- [ ] Lowish intensity of pumping light source (e.g. the colored flashlights)
- [ ] Pumping light source color needs to match energy difference from G to 1
- [ ] Pumping light source color needs to match energy difference from G to 2
- [ ] Pumping light source color needs to match energy difference from 1 to 2
- [ ] Longish lifetime for level 2
- [ ] Shortish lifetime for level 2
- [ ] Longish lifetime for level 1
- [ ] Shortish lifetime for level 1
- [ ] Mirrors at highish reflectivity

f. (0.5 pts) In an operational laser, which state has highest population of atoms in it?

G 1 2 All three have the same population

g. (0.5 pts) Which photons are being cloned to make the laser light?

- The photons emitted by the colored flashlights
- The photons emitted by transitions of the gas atoms from level 2 to G
- The photons emitted by transitions of the gas atoms from level 2 to 1
- The photons emitted by transitions of the gas atoms from level 1 to G

h. (essay) Explain what a population inversion is and why it is necessary to have a population inversion in a laser?

i. (essay) Explain why it would be impossible to achieve a population inversion and hence impossible to make a laser work if your design used an atom where only two energy levels were involved (the lowest or ground level and one higher level) and in your design you were pumping atoms into the excited state using light at the exact wavelength where the photon energy matched the energy separation between the lower and upper energy levels of the atom. (Note that: This is the reason that in actual lasers that use light to pump the atoms into the upper levels, three or four atomic energy levels are involved.)

j. (essay) Explain the function of the mirrors at each end of a laser. Why do you need them to have a functioning laser? What would happen if one mirror was removed?

k. You are designing a laser system and come across the following issues. Check all the actions you can take in order to restore good laser operation.

(0.75 pts) Case 1: The intensity of the pumping light source is reduced significantly.

- [ ] Use atoms with a longer lifetime for level 2
- [ ] Use atoms with a shorter lifetime for level 2
- [ ] Use atoms with a longer lifetime for level 1
- [ ] Use atoms with a shorter lifetime for level 1
- [ ] Increase mirror reflectivity
- [ ] Decrease mirror reflectivity

(0.75 pts) Case 2: The mirrors gets dirty and corroded, reducing their reflectivity.

- [ ] Increase the intensity of the pumping beam
- [ ] Decrease the intensity of the pumping beam
- [ ] Use atoms with a longer lifetime for level 2
- [ ] Use atoms with a shorter lifetime for level 2

- [ ] Use atoms with a longer lifetime for level 1
- [ ] Use atoms with a shorter lifetime for level 1

Explain your reasoning for why these options work for Case 2: